

THE TRANSFER OF ADAPTATION BETWEEN ACTUAL AND SIMULATED ROTARY STIMULATION

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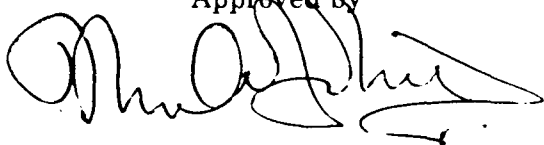
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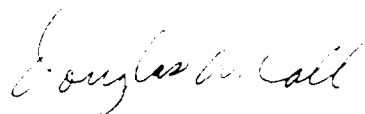
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The Transfer of Adaptation Between Actual and Simulated Rotary Stimulation

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It is well known that continued exposure to motion environments leads to adaptation, but it is not clear whether such changes are specific to the particular type of motion experienced. The present investigation sought to evaluate the extent of transfer between real motion and visually-induced apparent motion. In addition, the direction of motion was varied and these two factors, mode of exposure and direction of rotation, were examined in a cross-adaptational design. Thirty-two subjects were pre- and posttested on measures of disorientation after active bodily rotation and visually-induced self-vection. Two groups received ten consecutive trials of active bodily rotation (clockwise or counter-clockwise) for 4 consecutive days. Two other groups received ten consecutive trials of visually-induced self-vection (clockwise or counter-clockwise) in a rotating drum for 4 consecutive days. During the exposure phase, dizziness and self-vection increased over trials for the groups exposed to the drum, while dizziness remained unchanged over trials for the groups exposed to bodily rotation. Repeated exposure to bodily rotation resulted in improved walking performance over trials and days. Subjects exposed to bodily rotation exhibited increased tolerance to visually-induced self-vection; however, exposure to visually-induced self-vection did not result in greater tolerance to bodily rotation. No support for directional specificity was evident.

IN PROVOCATIVE motion environments, disorientation often occurs, presumably because of a mismatch between the visual, vestibular, and somatic senses, and within the vestibular system. This commonly leads to motion sickness (1,12,15,16). For example, sailors new to the sea perform perceptual-motor tasks poorly in heavy seas (2,10), and astronauts experience space motion sickness (8,13,19). With repeated exposure these disorders abate, and adaptation to the

rearrangement of the sensory relationships is assumed to have occurred. The sailor achieves "sea legs" and the astronaut becomes more resistant to microgravity-induced illness. Adaptation in this context is not thought to imply a loss of sensitivity, but rather a recalibration of one or more of the dimensions of perceptual experience, requiring a remapping of the relationships between sensory inputs. Presumably, the greater the mismatch in sensory input, the more adaptation must take place and the longer it will take to fully adapt (12).

The practical importance of understanding adaptive mechanisms is obvious for military and industrial efforts. How well can operators adjust to unique motion environments and how long will they take to do so? Must operators readapt to non-motion environments after adaptation and does repeated exposure to a specific motion environment provide lasting benefits to personnel? While these questions are important, only a limited amount of experimental evidence has been marshalled to address these issues. Perceptual-motor experiments concerned with rearrangement of the visual field (20) have indicated that considerable adaptation takes place, active experience provides quicker and more extensive adaptation than passive experience, and considerable recovery is necessary to readapt to unaltered spatial arrangements. One question that has received some attention concerns the specificity of adaptation. Can personnel adapt to motion environments similar to those of concern or must they be identical to the target environment to be of benefit (14,16)? Does experience in a flight simulator result in adaptation to motion, beneficial to real world operation of the simulated aircraft, or is it counter-productive? If generalization occurs, is the quality of simulation an important factor, or can rough approximations suffice? Put simply, is adaptation general or specific?

While Reason and Brand (16) suggest that the bulk of research on adaptation supports the notion that adaptation is specific to the stimulus condition and does not provide diminished response to subsequent stimulation that is qualitatively different from that experienced during adaptation, there are some notable exceptions to

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this rule. Guedry (7) measured slow phase velocity nystagmus evoked by controlled head tilts in a rotating chair following CCW exposure in a slow rotation room (SRR) for 12 d. He found very little nystagmus with CCW testing but considerable response with CW testing. Although this appeared to be support for the specificity of adaptation, the response elicited by CW stimulation was significantly below pretest levels, suggesting considerable generalization from the CCW adaptation. Reason and Graybiel (17) reported that exposure to CCW rotation in a SRR led to reduced susceptibility to motion sickness when subsequent CW exposure was presented. This finding indicated that the effects of adaptation were quite general and not specific to the direction of rotation. However, these same investigators (18) reported that exposure to cross-coupled stimulation was both directionally specific and specific to the speed of rotation. In a recent review of issues pertinent to visually-induced adaptation (11), it was concluded that the study of adaptation is essential for an understanding of simulator sickness and more applied work on adaptation to real and visually-induced motion is necessary.

One recent attempt to address this question (5) involved training subjects, prone to motion sickness, to tolerate various forms of motion. Subjects were pre- and posttested on a rotating-tilting chair (cross-coupled Coriolis stimulation), a Dichgans and Brandt-type drum (visually-induced apparent motion) (3), and a VDT display intended to produce linearvection. The treatment groups ($N = 5$) received: (A) cognitive-behavioral counseling and Coriolis exposure; (B) cognitive-behavioral counseling and exposure to the drum; (C) cognitive-behavioral counseling and exposure to the VDT; and (D) cognitive-behavioral counseling only. The results indicated that training with the most provocative stimulus (Coriolis stimulation) afforded considerable tolerance to the other forms of stimulation, but this transfer was not observed when drum or VDT subjects were tested with the chair; thus, generalization was unidirectional. Some support for the specificity of adaptation was found in that the drum group showed improvement only for the drum test.

A previous study concerned exposure to actual, active bodily rotation and testing with visually-induced apparent self-rotation (9). Half of the subjects in the experimental group adapted to clockwise (CW) rotation and half adapted to counter-clockwise (CCW) rotation. An additional group was not exposed to bodily rotation. All were tested on both clockwise and counter-clockwise visual stimuli. The results indicated that, during the exposure phase, a considerable degree of adaptation occurred, as measured by post-rotary walking performance and magnitude estimates of dizziness. Subjects in the experimental group exhibited significantly lower estimates of dizziness than did controls when posttested in a Dichgans and Brandt-type drum. No significant differences, however, were found for direction of rotation. This, study, therefore, found support for the notion of transfer of adaptation, but no support for directionally specific transfer.

The current investigation was aimed at determining whether our previous results with motion sickness

counseling would be obtained with exposure to stimuli that do not normally elicit severe motion sickness responses. In addition we wished to extend the findings of Kennedy *et al.* (9) and particularly to address more closely the issue of specificity. As in that study, we asked if exposure to bodily rotation would transfer to conditions in which the body itself does not move, but in which a moving visual framework induces an apparent movement of the body. In addition, we asked if adaptation would transfer from exposure to a rotating visual framework, with a stationary subject, to exposure conditions involving an actively moving subject in a physically stationary visual framework. We also asked whether adaptation to one direction of rotation would result in diminished response to that specific direction or would generalize to the opposite direction of rotation. A cross-adaptation design was employed in which half the subjects were exposed to active body rotations, (CW or CCW) and the other half were exposed to a rotating drum (CW or CCW) that induced an apparent rotation of the body. Adaptational effects were assessed by comparing differences between pre- and posttest measures of dizziness, rotary velocity, and heel-to-toe walking.

METHODS

Subjects

We recruited 32 subjects from the University of New Orleans; 17 were female and 15 were male. They ranged in age from 18 to 30 years. Each was selected on the basis of questionnaires indicating that their medical histories were devoid of significant pathology. Subjects were screened with the drum test (see below) to determine that they found this type of stimulation disorienting.

Stimulation

Two modes of stimulation were employed. The first (DRUM) was accomplished by seating the subject inside a circular drum 5 ft in diameter and 4 ft in height with a mirrored ceiling. The inner surface of the drum was lined with alternating black and white vertical stripes, 6 in. wide. With appropriate fixation, the entire visual field was stimulated; rotation of the drum at 10 rpm produced a compelling illusion of circular self-motion. Subjects were asked to indicate when self-vection occurred and then to tilt their heads laterally 75° to the left and right at a rate of 1 cycle per s or Hz. The second type of stimulation (SPIN) was that employed by Kennedy *et al.* (9). It involved having the subject bend at the waist to a 45° angle with one hand pointing at the floor. The other arm was extended across the chest, under the pointing arm, to grip the contralateral earlobe. This assured that the subject maintained a fairly stable position during bodily rotation. Each subject then stepped in a circular fashion around the point on the floor to which he or she was pointing and continued to turn until 10 revolutions were completed. Two assistants assured that the subject did not fall and gave feedback to assure that the 10 revolutions were completed within a 1-min period. The floor and surrounding

walls were padded with exercise mats for the protection of the subject.

While the two modes of stimulation were quite similar in terms of the speed of rotation (10 rpm), they differed in that one involved active bodily rotation and the other involved passive rotation of the visual field. In addition, the drum stimulation also involved alternating roll axis stimulation ($\pm 75^\circ$) through active head movements during exposure to the visual stimulation.

Pre- and Posttesting

All subjects were first pretested in the drum on Day 1. Each trial was 30 s in duration and two trials were run in each direction. Drum direction was alternated and half the subjects began in the CW direction (DR), while the other half began CCW (DL). Subjects were asked to give a magnitude estimate (0–20) of dizziness upon the cessation of each trial. They were also asked to give a magnitude estimate (0–20) of the velocity of visually-induced self-motion. Subjects whose estimates were less than 4 or greater than 16 were excluded from the experiment. On Day 2 all subjects were pretested on spinning. Two trials were performed in each direction. Half the subjects grasped their left earlobe and half grasped their right earlobe. Within these groups half spun first in the CW (SR) direction, the other spun first in the CCW (SL) direction. After each trial they were quickly guided to the start of a line painted on the floor (2 in. by 9 ft) and asked to walk along the line in a heel-to-toe fashion. The number of correct steps was recorded (0–9) and they were then asked to give a magnitude estimate (0–20) of the dizziness they had experienced immediately after cessation of spinning. Posttesting was carried out in the same fashion as pretesting on Days 7 and 8.

Exposure Conditions

After pretesting, the 32 subjects were randomly assigned to 4 groups ($n = 8$), approximately balanced for age and gender. Two groups were exposed to the DRUM rotating CW (DR) or CCW (DL); the other two groups were exposed to SPIN rotating CW (SR) or CCW (SL). On each of 4 consecutive days (Days 3–6), 10 exposure trials were carried out. Each trial lasted 30 s and was followed by magnitude estimates of dizziness and self-vection (DRUM groups) or magnitude estimates of dizziness, and heel-to-toe walking (SPIN groups). As soon as posttrial measures were taken the next trial was initiated. Reductions in estimates of dizziness and self-vection and increases in the number of steps taken during heel-to-toe walking indicated adaptation to stimulation.

RESULTS

Exposure Conditions

The data from the exposure sessions were submitted to analysis of variance (4). Mean magnitude estimates of dizziness as a function of trials, for all four groups, are presented in Fig. 1. It is apparent that significant increases in dizziness occurred across trials for the DRUM group, while the SPIN groups exhibited no significant changes in dizziness across trials, which was

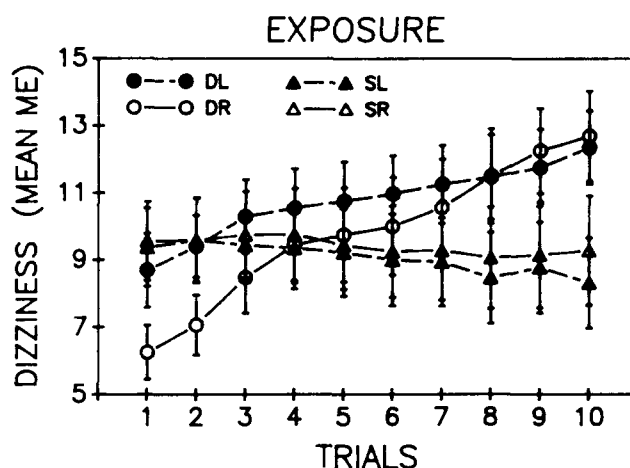


Fig. 1. Mean magnitude estimates of dizziness as a function of trials for each exposure group. DL = drum left; DR = drum right; SL = spin left; SR = spin right.

supported by a significant group by trials interaction [$F(27,252) = 9.25$; $p < 0.0001$]. Thus, this measure offers no support for the notion that exposure to either DRUM or SPIN resulted in decreases in dizziness. There was a significant main effect for trials [$F(9,252) = 12.25$; $p < 0.0001$] indicating greater overall dizziness on trial 10 relative to trial 1, but no other main effects or interactions were significant.

The magnitude estimates of self-vection for the two DRUM groups indicated that the CW drum group exhibited a greater increase in self-vection across trials than did the CCW group. This might be explained in terms of an equipment anomaly.¹ Analysis of variance for the two DRUM groups revealed a significant main effect for trials [$F(9,126) = 14.31$; $p < 0.0001$], indicating greater self-vection for trial 10 relative to trial 1. In addition, a significant interaction for groups by trials [$F(9,126) = 2.96$; $p < 0.0031$] resulted, indicating that the CW group increased estimates of self-vection more than the CCW group (as noted above). A second interaction, days by trials, was significant [$F(27,378) = 1.58$; $p < 0.0344$], indicating that the increase in self-vection across trials diminished with days. The second interaction is depicted in Fig. 2. Clear-cut increases in this estimate are apparent across trials and although the interaction was significant, no systematic change in the slope is apparent across days. As with dizziness, there is little support for the notion that exposure resulted in decreased self-vection within or between days. No other main effects or interactions were significant.

The mean number of steps as a function of trials and days is presented in Fig. 3. For the most part, steps increase across trials and days, indicating that ability to walk after spinning did increase after exposure within and across days. For the walking test (SPIN groups),

¹During exposure, the drum group which was exposed to the drum right (CW) stimulation exhibited significantly greater magnitude estimates of self-vection across trials than did the drum group receiving drum left (CCW) stimulation. We think this could have been related to the fact that the stationary chair was positioned 4 in. to the right of center to allow easy access to the chair. Why such asymmetry of stimulation would result in different degrees of self-vection over trials is not readily apparent and is deserving of future experimentation.

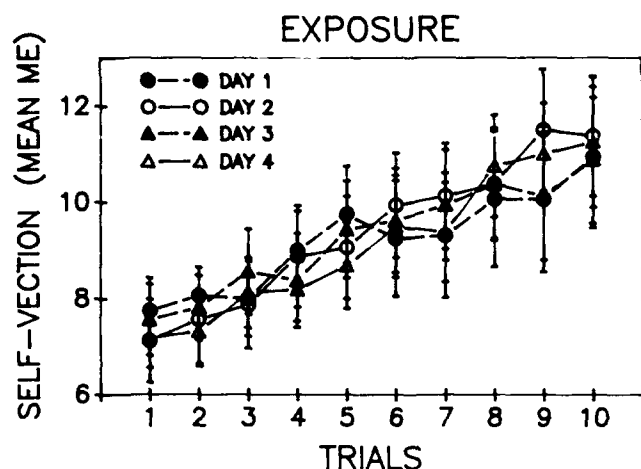


Fig. 2. Mean magnitude of self-vection as a function of trials over days.

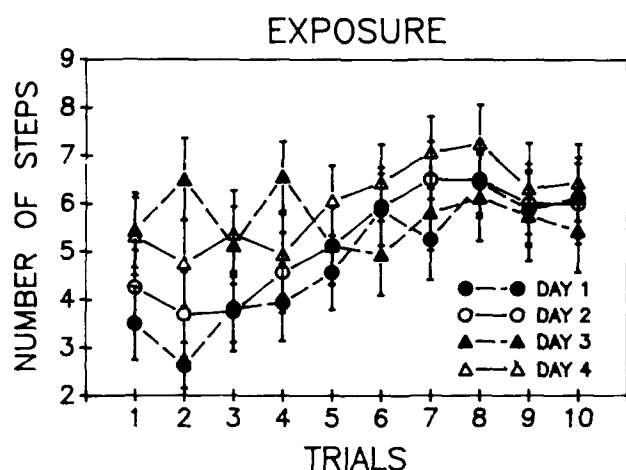


Fig. 3. Mean number of steps as a function of trials over days.

analysis revealed a significant main effect for days [$F(3,42) = 3.27$; $p < 0.0303$], indicating better walking across days, and a significant main effect for trials [$F(9,126) = 7.00$; $p < 0.0001$], indicating better walking over trials. A significant interaction for days by trials [$F(27,378) = 1.69$; $p < 0.019$] was found supporting the observation above that walking improved with both trials and days. No other main effects or interactions were significant.

Pre- and Posttesting

The data obtained with the DRUM and SPIN tests were analyzed in separate analyses of variance designs. These analyses were mixed, five factor designs with mode (drum or chair) and direction of exposure (left or right) as between subject factors and test (pre or post), trials (1 or 2), and direction of test (same or different²) were within subject factors.

DRUM tests: The mean dizziness scores for pre- and

²In coding the data, we defined *same* and *different* with regard to the direction of vection experienced in the drum and while spinning. Thus, when the drum was rotated CW, CCW apparent motion was experienced and vice versa. In the case of CW spinning, CW motion was experienced.

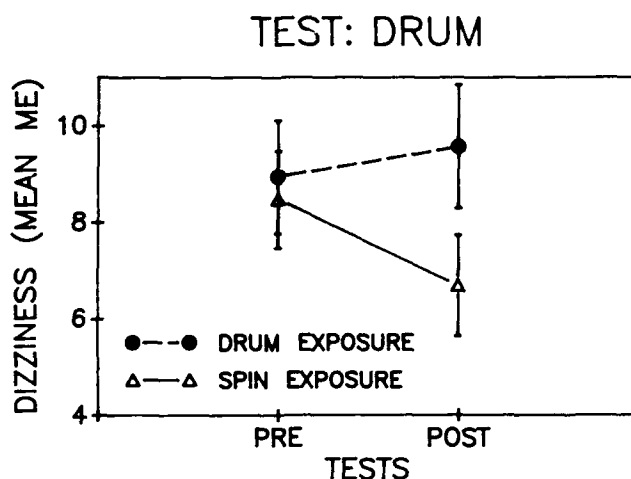


Fig. 4. Mean magnitude estimates of dizziness as a function of pre- and post-exposure drum testing for each mode of exposure.

posttesting for DRUM and SPIN groups (collapsed across direction) are presented in Fig. 4. It is clear that dizziness declined from pre- to posttesting for subjects that experienced actual bodily rotation during exposure (Newman-Keuls' $p < 0.01$), but did not differ from pre- to posttesting if subjects experienced DRUM rotation during exposure. These data support the notion that transfer of adaptation³ occurred in the SPIN groups, but not in the DRUM groups. No support for directional specificity of adaptation was evident in that the direction of rotation did not prove to be a significant variable. The mean magnitude estimates of dizziness from pre- to posttesting for groups tested in the same and different direction of rotation on the first and second trial are presented in Fig. 5. Some support for directional specificity was evident, in that the SPIN subjects exhibited less dizziness pre- to posttesting if they experienced vection in the same direction during exposure and testing on trial 1 (Newman-Keuls', $p < 0.01$). However the strength of this support is weakened in that this same trend was not replicated on trial 2. Analysis of variance for DRUM testing revealed significant main effects for direction of vection during exposure [$F(1,28) = 8.08$; $p < 0.0083$], and direction of vection during testing [$F(1,28) = 7.80$; $p < 0.0093$]. The first effect was due to the fact that more dizziness was experienced with CCW stimulation¹ and the second derived from the fact that more dizziness during testing was experienced when subjects were stimulated with different as opposed to the same vection experienced during exposure. In addition, significant interactions for mode of exposure by pre-post [$F(1,28) = 7.78$; $p < 0.0094$] and trials by direction of vection during test by pre-post [$F(1,28) =$

³While we have conceptualized the effects of exposure to our stimuli in terms of adaptation and the transfer thereof, one reviewer has suggested that, since actual bodily rotation was more provocative (see Fig. 4 and 6—pretest), our posttest results might better be interpreted in terms of contrast effects. In addition, this reviewer suggested that the increase in steps noted during exposure to SPIN might be the result of training and not adaptation. If this were the case our conclusions regarding transfer of adaptation would be mitigated. Perhaps future experiments that seek to equate different modes of exposure in terms of provocation will shed some light on the comparative validity of these alternate interpretations.

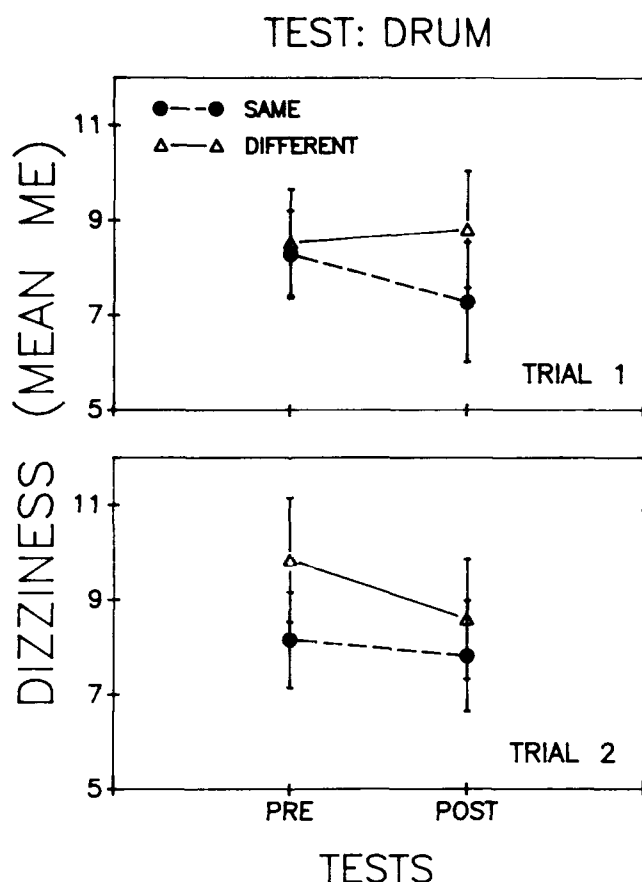


Fig. 5. Mean magnitude estimates of dizziness as a function of pre- and post-exposure drum testing for same and different directions of rotation in terms of test/exposure combination. Upper panel = Trial 1; lower panel = Trial 2.

8.95; $p < 0.0057$) were obtained. These interactions are plotted in Fig. 4 and 5. Analysis of the magnitude estimates of self-vection did not reveal any significant main effects or significant interactions.

SPIN tests: The mean magnitude estimates of dizziness for the DRUM and SPIN groups (collapsed across directions) are presented in Fig. 6. It is clear that the SPIN groups showed pre-post declines in dizziness on

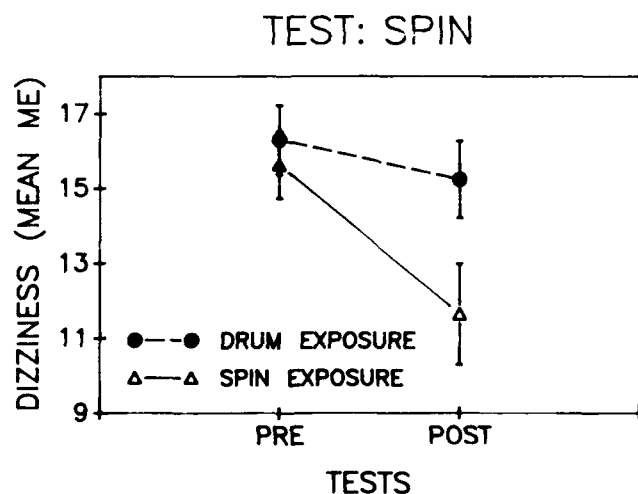


Fig. 6. Mean magnitude estimates of dizziness as a function of pre- and post-exposure spin testing for each mode of exposure.

the SPIN test (Newman-Keuls', $p < 0.0001$), suggesting that adaptation occurred. No transfer of adaptation from DRUM to SPIN tests occurred. Thus, some evidence for specificity of transfer was found in that subjects experiencing actual bodily rotation during exposure were less dizzy when tested with that same type of rotation, but no evidence for specificity of direction of rotation was observed. The mean magnitude estimates of dizziness for groups experiencing the same and different rotational directions for the DRUM and SPIN groups are presented in Fig. 7. These results can be interpreted as support for adaptation in that the SPIN subjects exhibited less dizziness when tested with actual bodily rotation than did the DRUM subjects. Further, SPIN subjects exhibited less dizziness when tested in the same, as opposed to the opposite, direction of rotation as experienced during exposure (Newman-Keuls', $p < 0.0001$). This result offers some support for directionally specific transfer of adaptation. Analysis of variance revealed significant main effects for pre-post [$F(1,28) = 27.74$; $p < 0.0001$] and direction of rotation during testing [$F(1,28) = 12.86$; $p < 0.0013$], as well as significant interactions for mode of exposure by pre-post [$F(1,28) = 9.30$; $p < 0.005$] and mode of exposure by direction of rotation during testing [$F(1,28) = 12.10$; $p < 0.0017$]. The former interaction is depicted in Fig. 6, and the latter in Fig. 7.

The mean number of steps from pre- to posttesting for the DRUM and SPIN groups (collapsed across direction) are presented in Fig. 8. Some support for adaptation is apparent in that the number of steps increased from pre- to posttesting for the SPIN groups (Newman-Keuls', $p < 0.001$), but no support for directional specificity was found. Analysis of variance for the walking test revealed a significant main effect for pre-post [$F(1,28) = 10.92$; $p < 0.0026$], as well as, a significant interaction for pre-post by mode of exposure [$F(1,28) = 10.65$; $p < 0.0029$]. This interaction is depicted in Fig. 8.

DISCUSSION

Three major observations regarding adaptation are clear from these results. First, exposure to the drum did

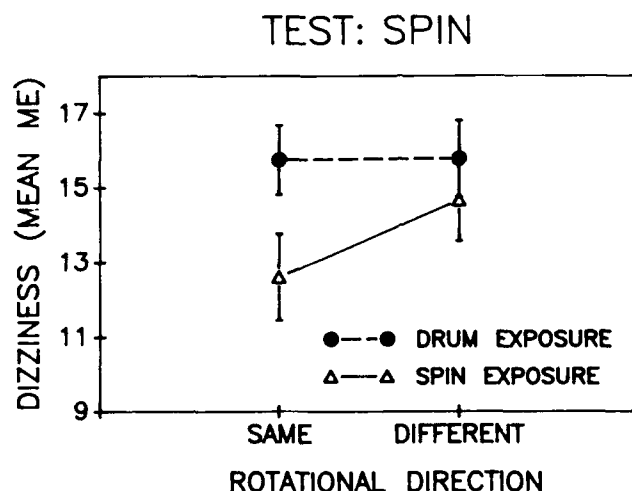


Fig. 7. Mean magnitude estimates of dizziness as a function of same and different directions of rotation in terms of test/exposure combination for each mode of exposure.

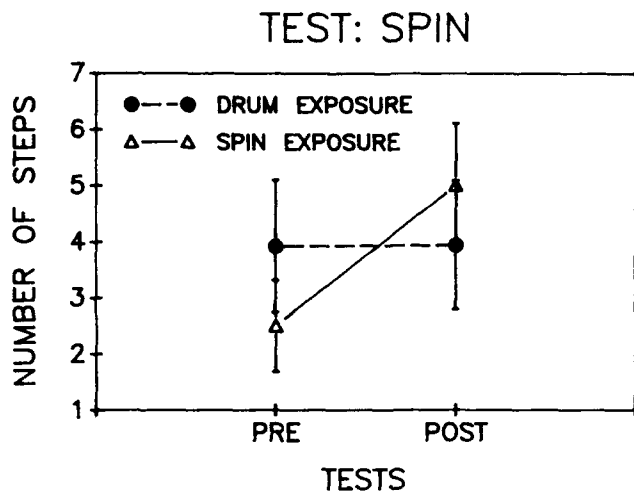


Fig. 8. Mean number of steps as a function of pre- and post-exposure spin testing for each mode of exposure.

not produce any adaptation. The finding that dizziness and self-vection increase across DRUM trials is in agreement with previous findings in our laboratory which found similar increases across trials with magnitude estimates of motion sickness and self-vection (6). The present results are not in agreement with this previous work in that no significant declines in estimates of self-vection across days occurred. The pre- and posttest measures indicated little support for the belief that adaptation occurred in the DRUM groups.

Second, exposure to bodily rotation did produce adaptation. The finding that dizziness estimates remained stable across SPIN trials is contrary to the finding of Kennedy *et al.* (9) in that they found significant changes within and between sessions on measures of dizziness. Our findings with heel-to-toe walking agree with this previous report, however, in that increased scores were found to occur over trials in both studies.

Third, transfer of adaptation from the DRUM to the SPIN test did not occur in the DRUM groups. However, considerable support for transfer of adaptation was found in the SPIN groups. Regarding whether transfer of adaptation depends on the specific direction of rotation, very little support can be marshalled from the data provided by any of the groups on either test. This suggests that some degree of transfer of adaptation to disorienting motion can be achieved with inexpensive rotational stimuli. These findings are in agreement with our previous study using motion sickness tolerance and cognitive-behavioral counseling in that those results also indicated that adaptation to Coriolis stimulation transfers to visually-induced apparent motion, but adaptation to visually-induced motion did not transfer to Coriolis stimulation (5). Collectively, these results suggest that adaptation occurs and transfers when actual vestibular stimulation is employed, but not when motion is simulated visually.

There were a number of differences between the methods of Kennedy *et al.* (9) and the current study. In their study, the walking test was easier (2 ft by 7 ft). This might explain why the mean performance of our subjects did not achieve optimal levels. It is possible that such success is necessary if large increases across

days are to be expected. In their study, magnitude estimates of dizziness were obtained using a 10-point rating scale prior to the walking test. By requiring a subjective rating before walking, it is possible that they elicited a rating which was less contaminated than ours by information about walking ability. Another difference was that their subjects were told to assign the highest rating to the dizziness they experienced with the pretest. This disallowed any ratings of dizziness in excess of those experienced at pretest. Thus, their procedures precluded observation of changes which increased over trials and may have indicated to the subjects that declines were expected. Finally, their subjects were asked to give a magnitude estimates of dizziness after each head movement in the drum, while our subjects gave a single magnitude estimate of dizziness after each trial. If dizziness increased within a trial, averaging estimates within a trial might yield estimates which would be expected to be lower than estimates taken after a trial. This, however, cannot explain why our subjects indicated increases in dizziness across trials, while their subject's scores declined.

The most parsimonious conclusion which can be reached from this study is that considerable adaptation to disorienting rotary stimulation occurs, as evidenced by pre-post test scores, despite the lack of reductions in dizziness during the exposure phase. However, this adaptation and the transfer of adaptation from SPIN to DRUM appears to be of a general nature and is not linked tightly to the specific characteristics of the motion involved. This implies that the major benefit to be accrued from various visual simulation devices is in the area of operational training procedures and any benefit for motion adaptation may require vestibular stimulation during training.

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